UVa
Center for Applied Biomechanics

Development of a Test Methodology to Evaluate Mine Protective Footwear

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December 2004

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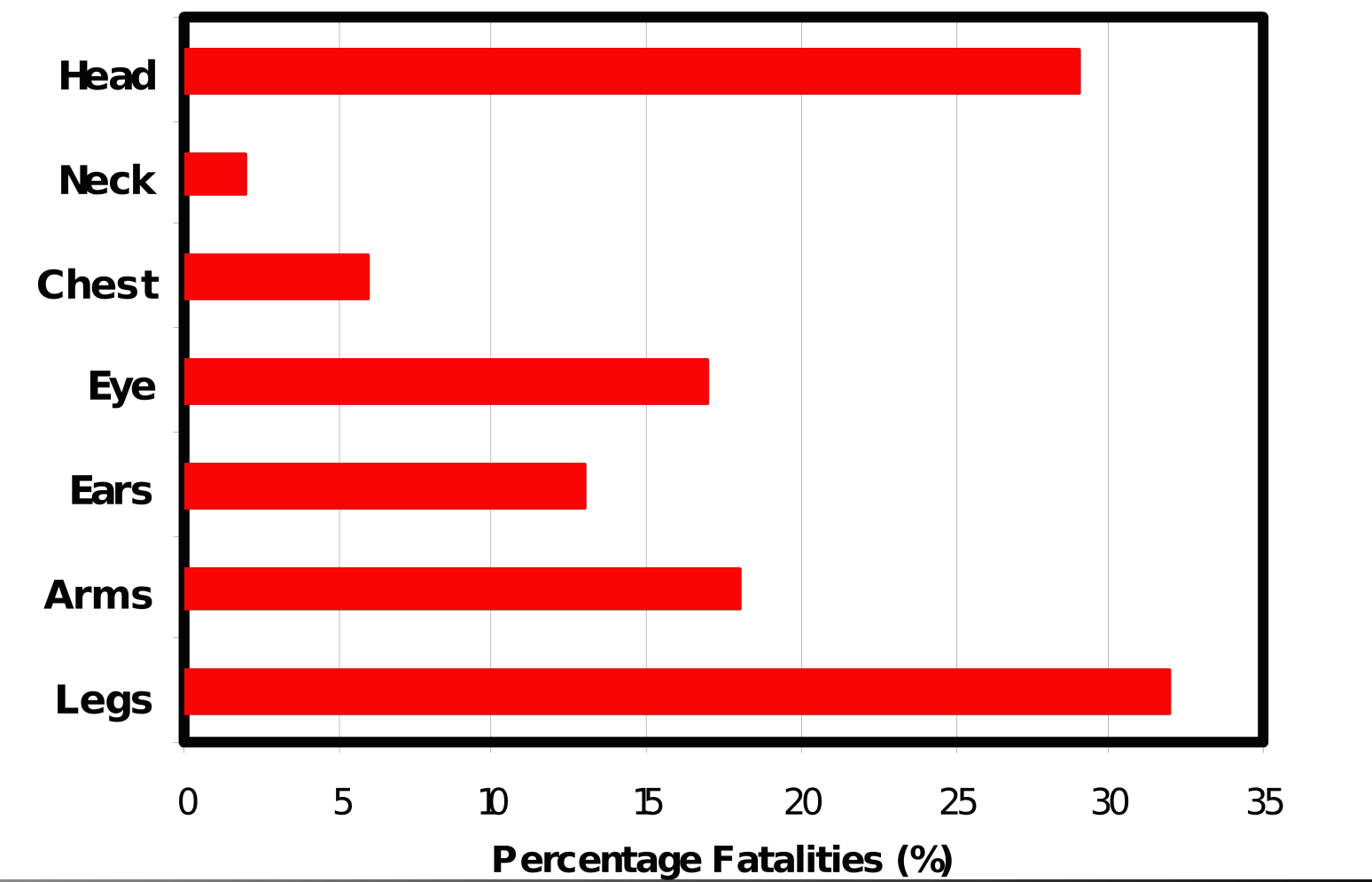
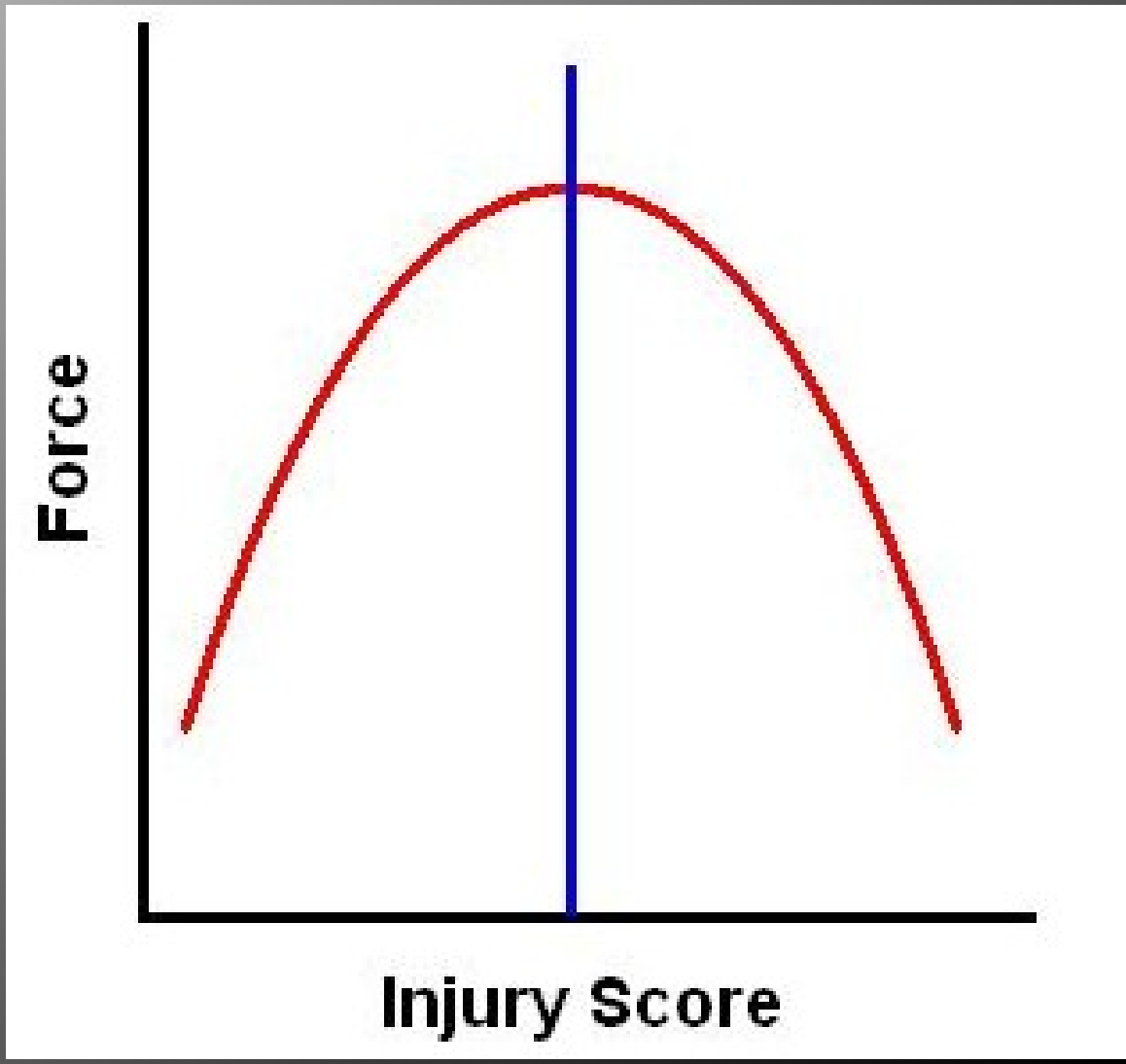
Background - Epidemiology



Source: Landmine Casualty Data Report - 2000

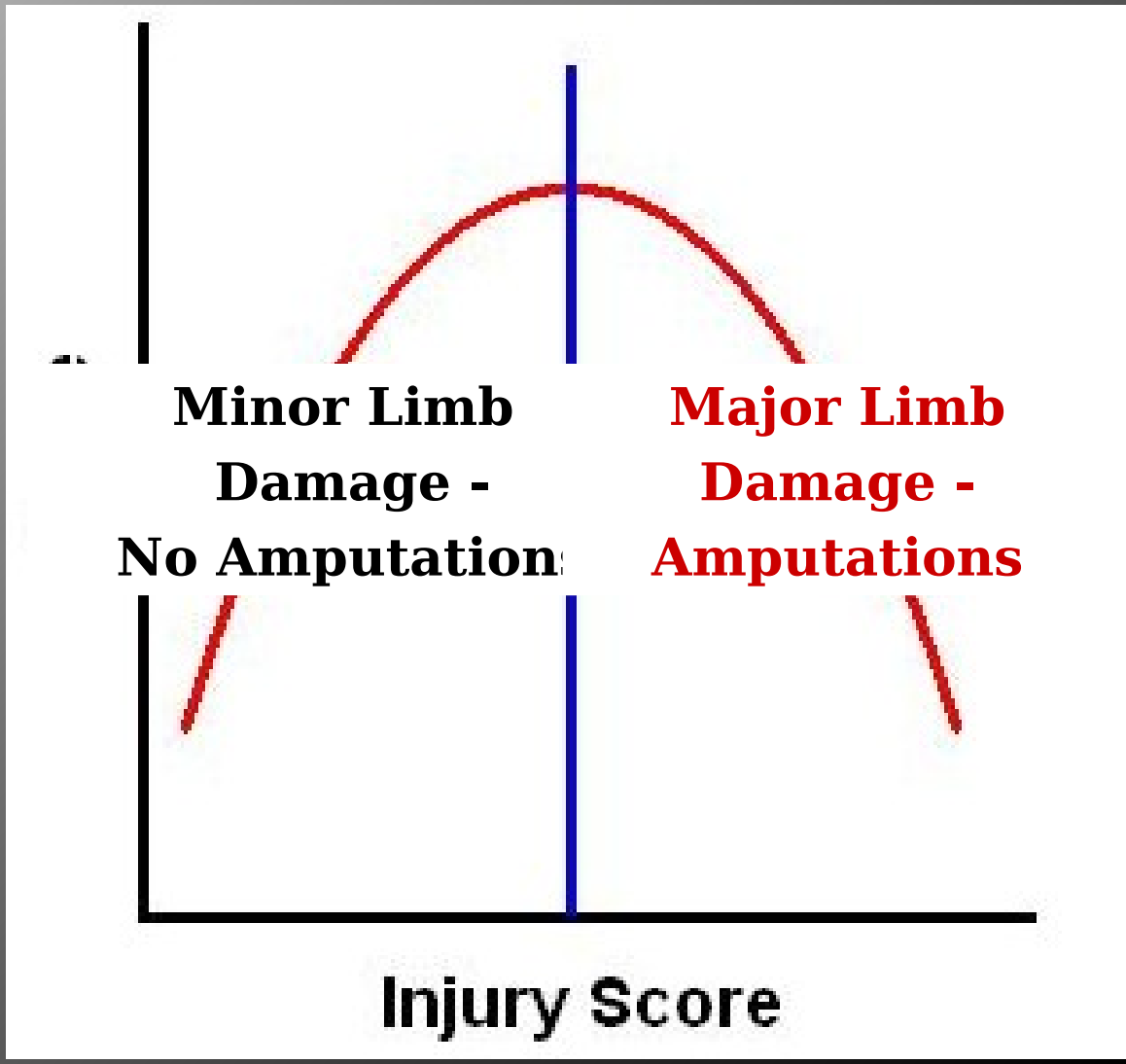
Background – Previous Testing

- LEAP 2000
  - Tested cadaveric limbs placed on anti-personnel landmines



Background – Previous Testing

- LEAP 2000
  - Tested cadaveric limbs placed on anti-personnel landmines
  - Destroyed and deflagrated test limbs



Objective Test Methodology

Transfer Function

Surrogate Physical Response

Loads,Acceleration, etc.

Injury Model

Animal Model
Cadaver Model
Epidemiology

Physical Response

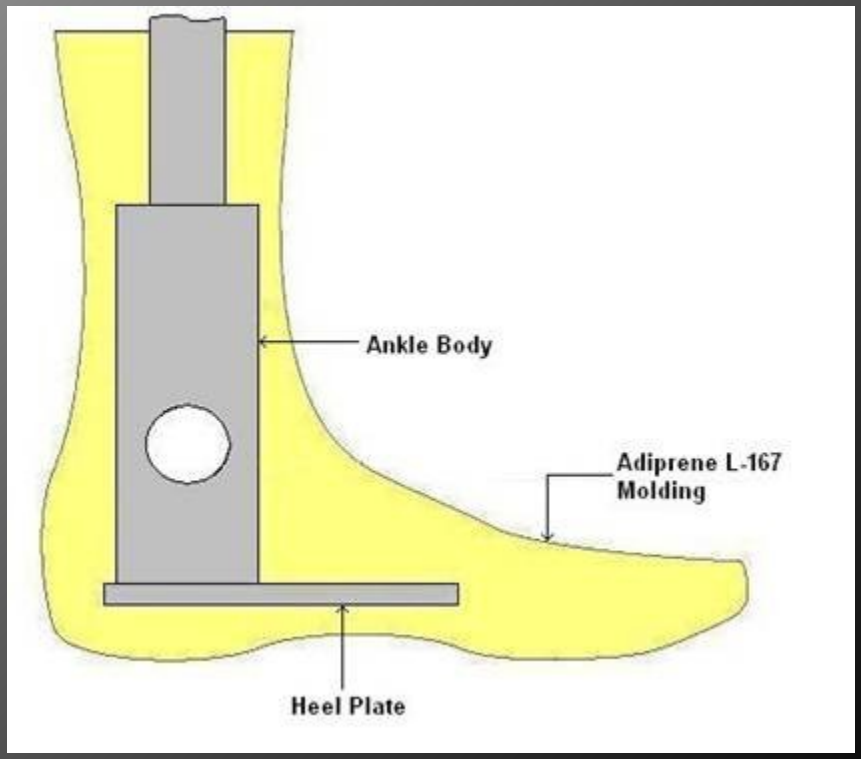
Loads, Damage, etc.

Test Setup – Test Fixture

- Culmination of Collaborative Efforts by Several Research Institutions
  - DRDC - Suffield
    - dummy surrogate foot
  - DRDC - Valcartier
    - translating test fixture
  - Aberdeen Testing Center
    - test fixture base
  - University of Virginia
    - synthesis, instrumentation: load cells and load cell mounts

Test Setup

- DRDC - Suffield – Surrogate Dummy Foot Design
- Modified by UVa

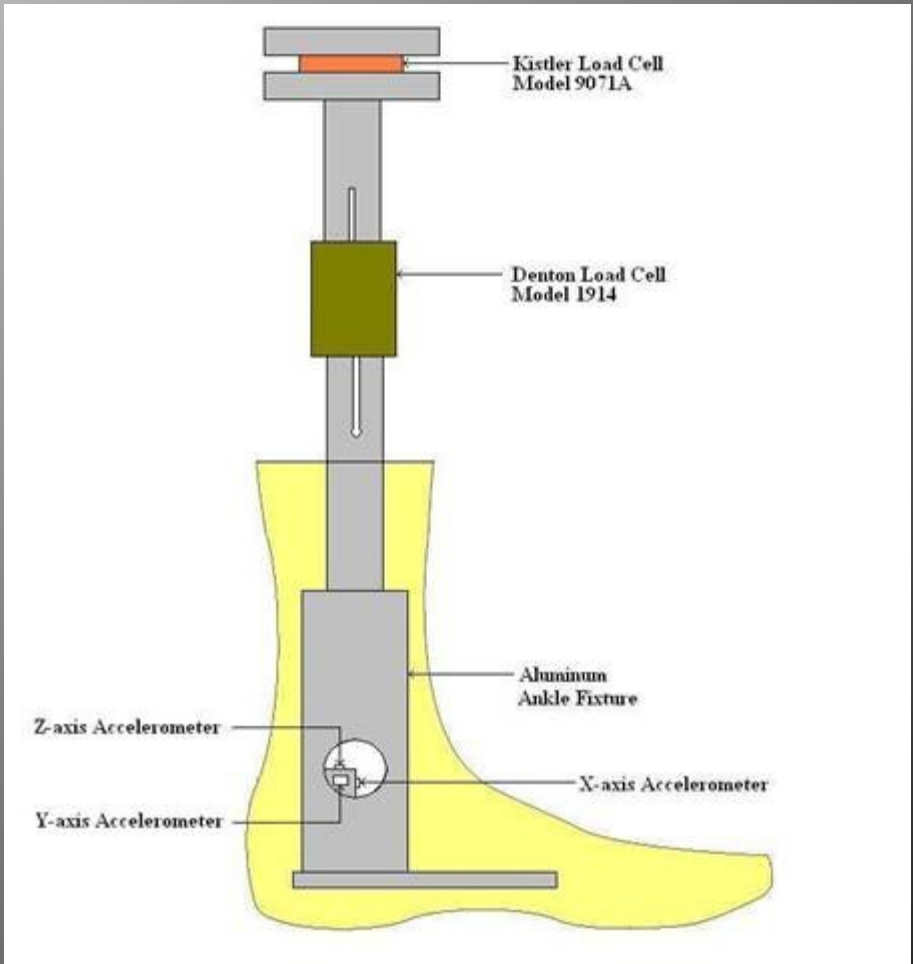


Test Setup

- DRDC Valcartier Design
- Modified by UVa
  - Adapted to ATC fixture
- Translating Crosshead
  - axial motion only
- Position
  - Standing, below

Test Setup

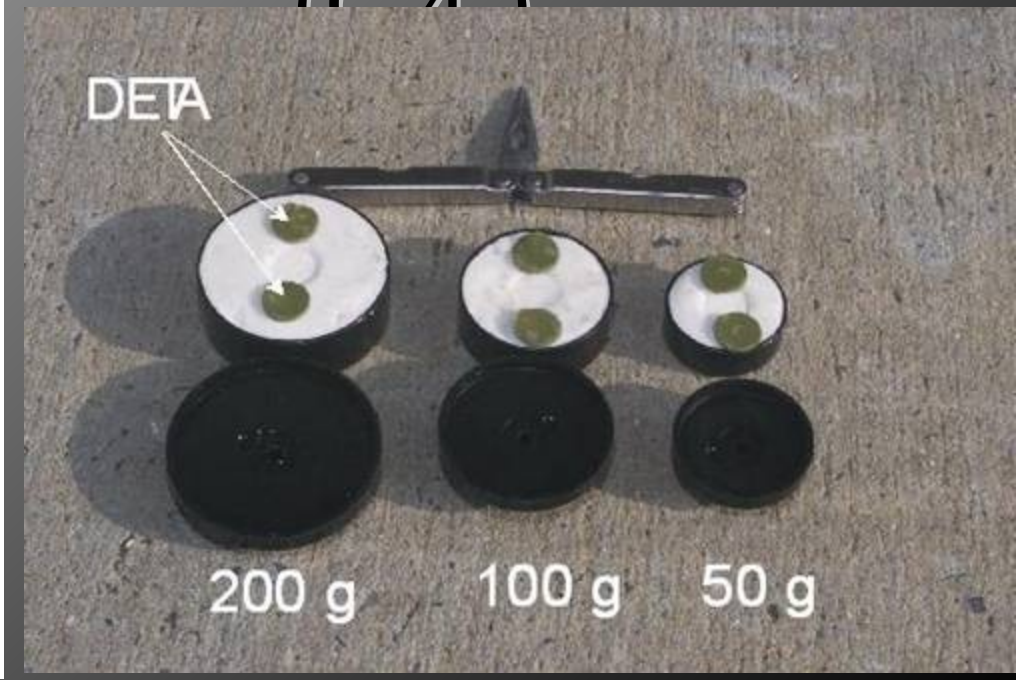
- UVa/ATC - Instrumentation



Test Setup - Mines

- PMN

- Simulated AP Landmines (C-4)

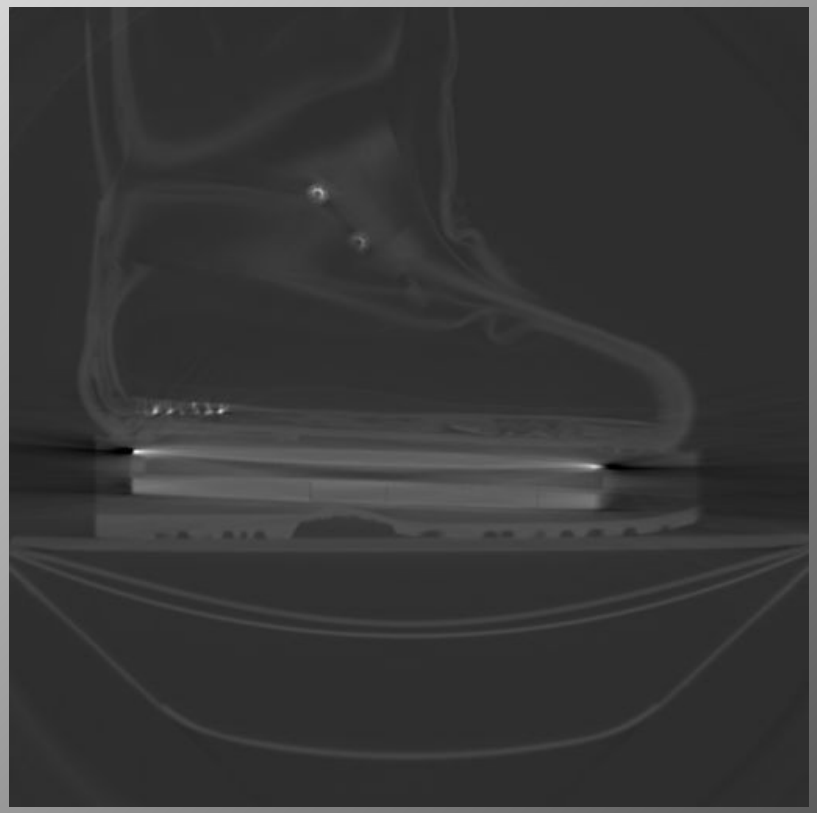


Boots (Radiographs)

- A

- B

Boots (Radiographs)



- E

- ME1

Specimen Test Matrix

- Male Specimens (Average age = 62 years)
  - Average body mass = 70.9 ± 6 kg
  - Average stature = 1760 ± 70 mm

Boot\Chargе	25 g	50 g	75 g	100 g	200 g
A	3	2	1		
B			1		
E			1		
ME1			3	3	1
ME2					5

Note: Structure and performance of ME1, ME2 similar for mine protection,

Video

Test 2: B (boot type), 75 grams (C-4)

Intact Foot/Lower Extremity

Test 1: ME1 (boot type), 75 grams

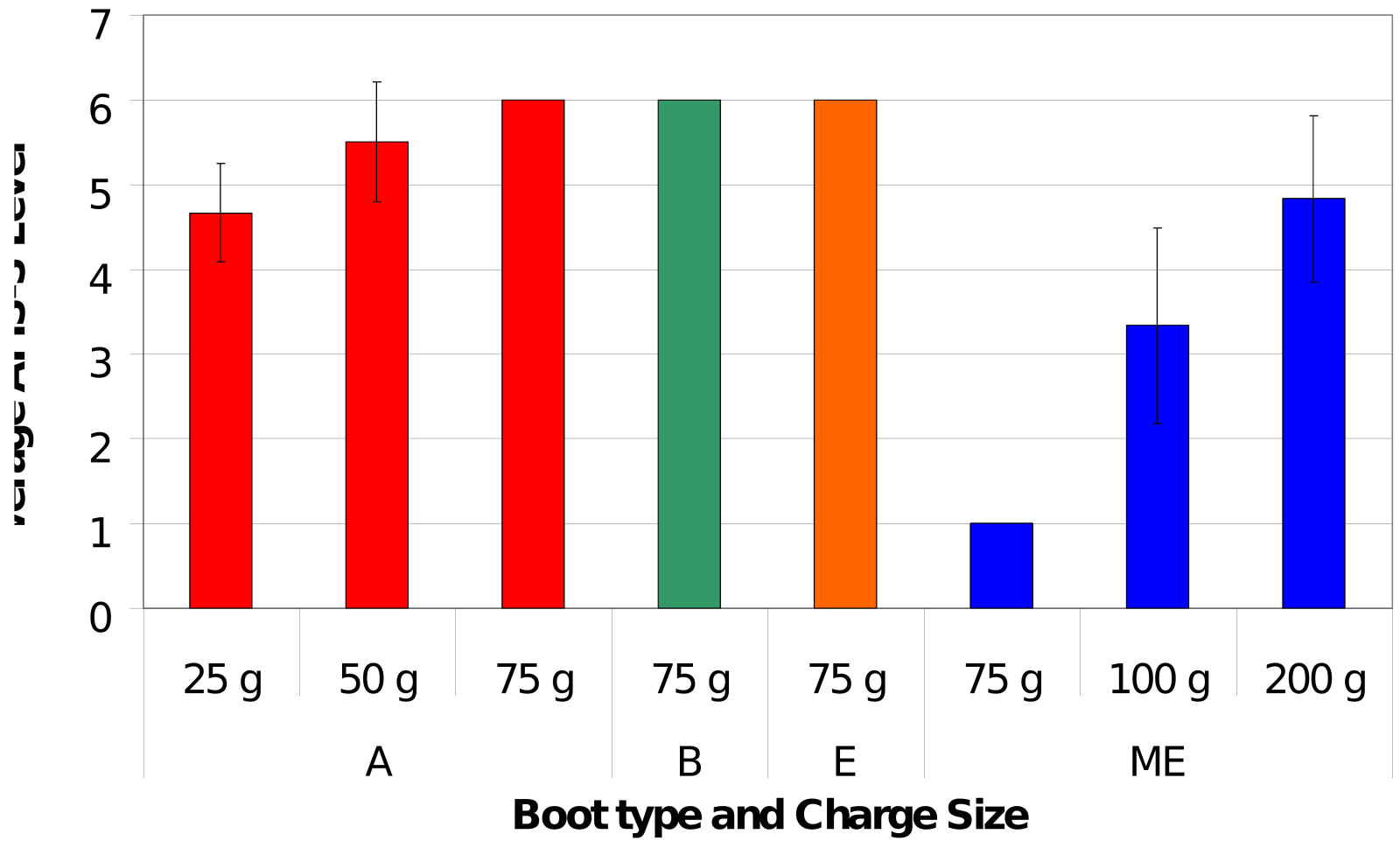
Typical Crushing Injury

Test 4: A (boot type), 75 grams (C-

Typical Injuries

Boot Type	General injury Description
B (75g)	major disruption of hindfoot
E (75g)	absence of hindfoot
A (25g, 50g, 75g)	shattered hindfoot / disruption of ankle / comminuted calcaneus / distal tibia fracture / tibial plateau fracture
ME1 (75g, 100g, 200g)	no injury / calcaneus fracture / tibial lip fracture / talar dome fractures / femoral condyle fractures / pilon fractures
ME2 (200g)	proximal tibia fractures / distal tibia fractures / comminuted calcaneus / talar fractures / pilon fractures

Injuries – AFIS-S



Boot Damage

Boot Damage Levels	Description of Damage Levels
BD1	Minor damage to boot (i.e. portion of sole blown off; insole destruction)
BD2	Structural damage to boot (i.e. minor blast penetration into foot compartment of boot)
BD3	Breach (i.e. massive blast penetration into foot compartment of boot)

Boot Damage Level 1

- Boot Type ME1

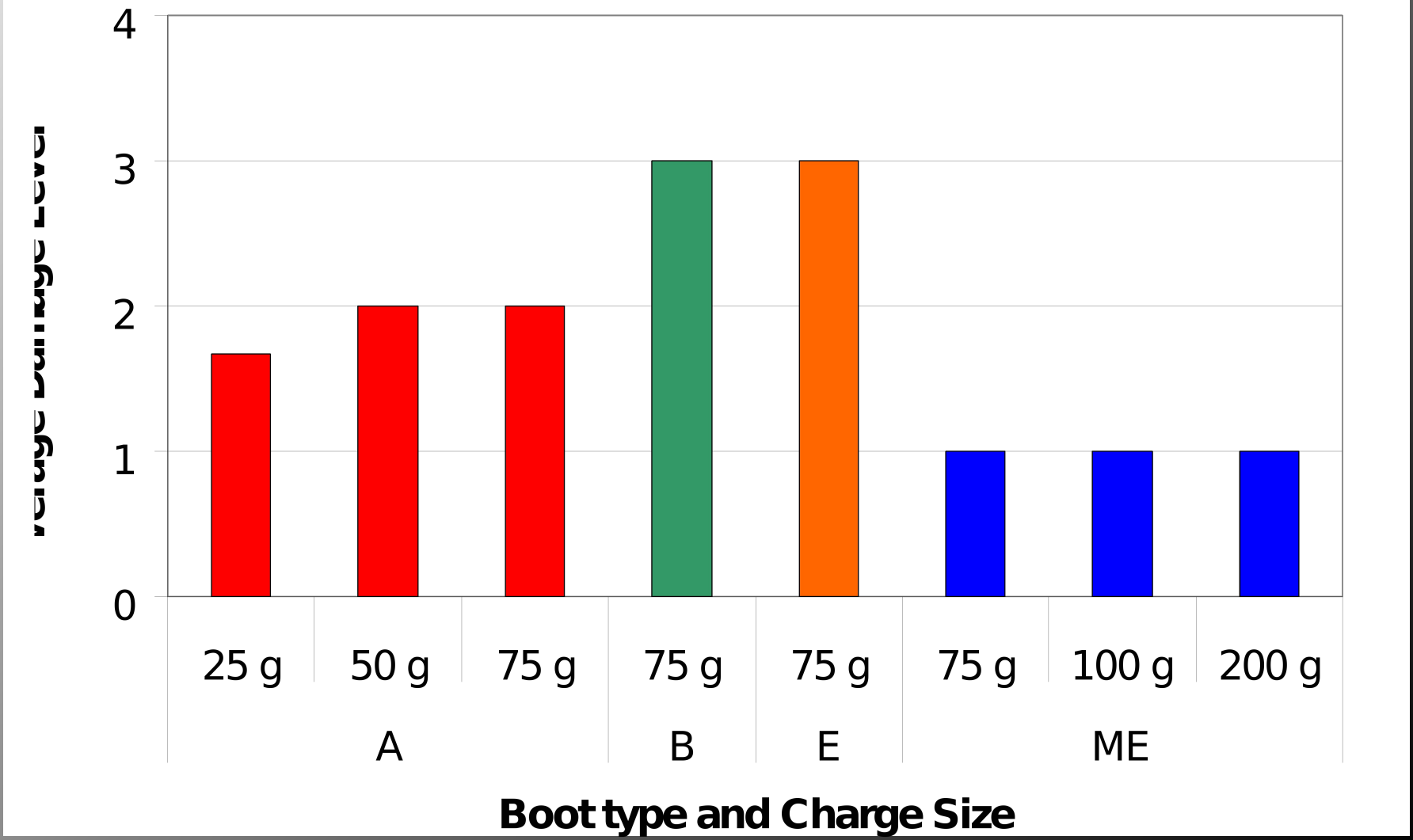
Boot Damage Level 2

- Boot Type A

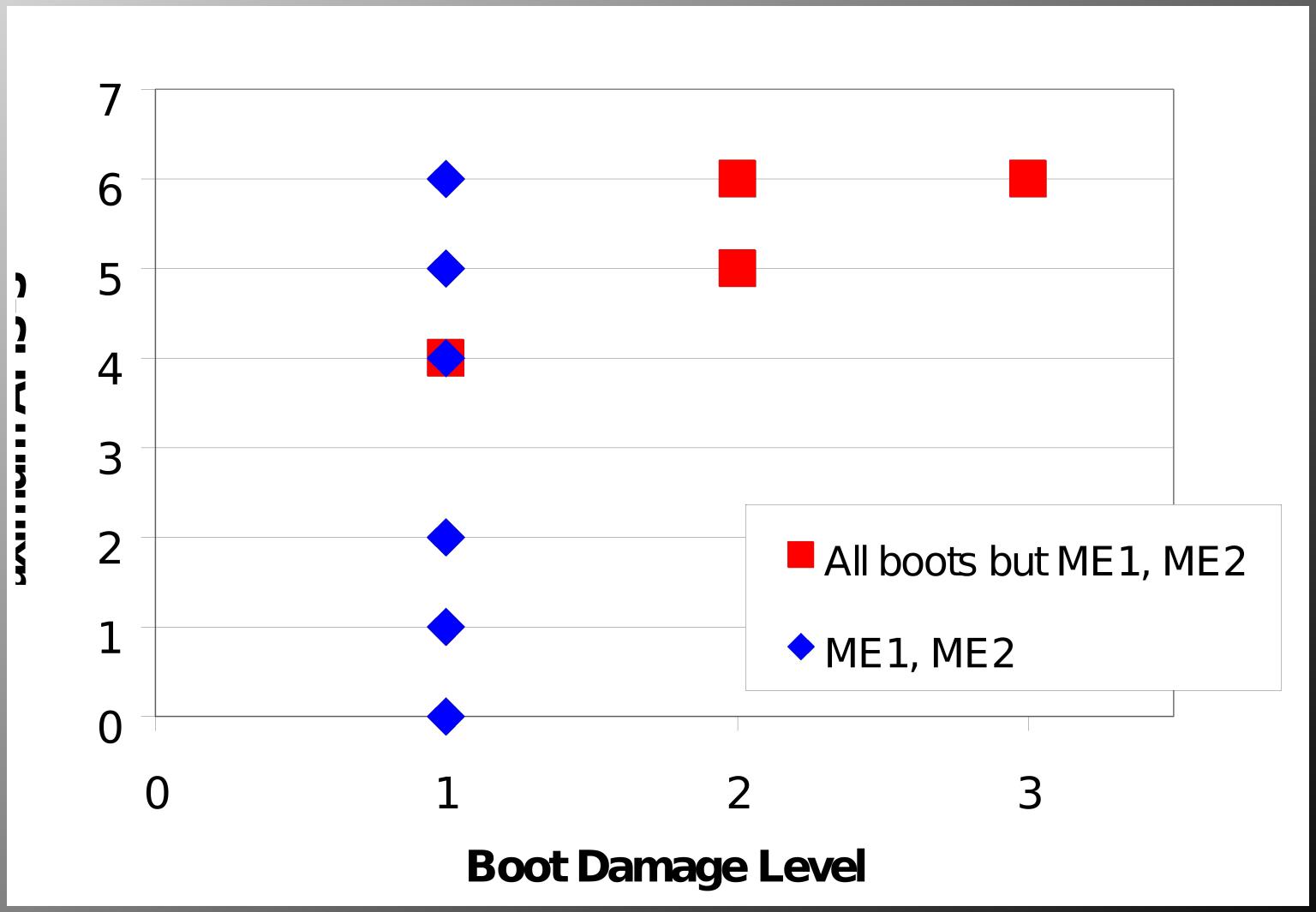
Boot Damage Level 3

- Boot Type B

Boot Damage (Averages)



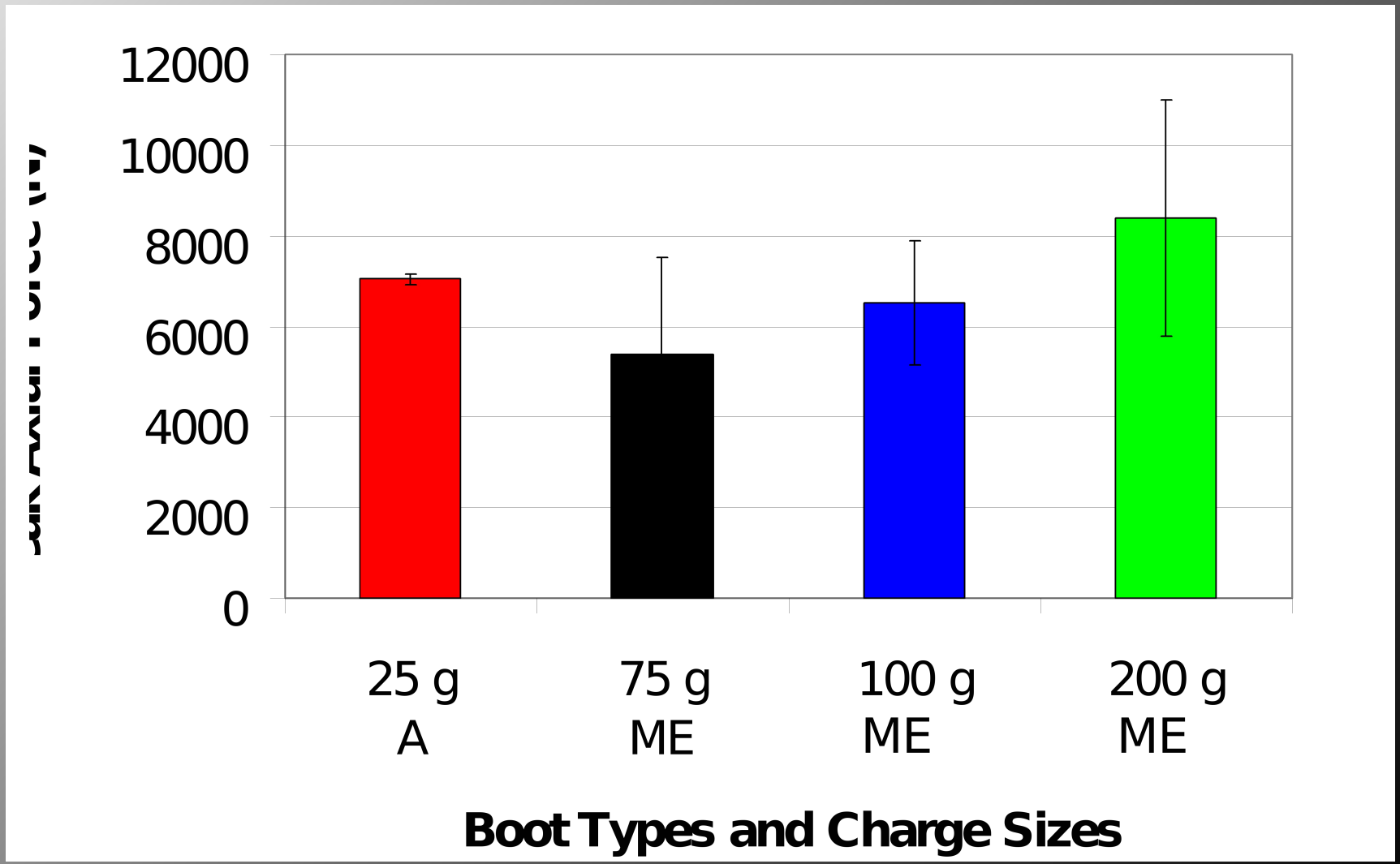
Boot Damage Level vs. AFIS-S



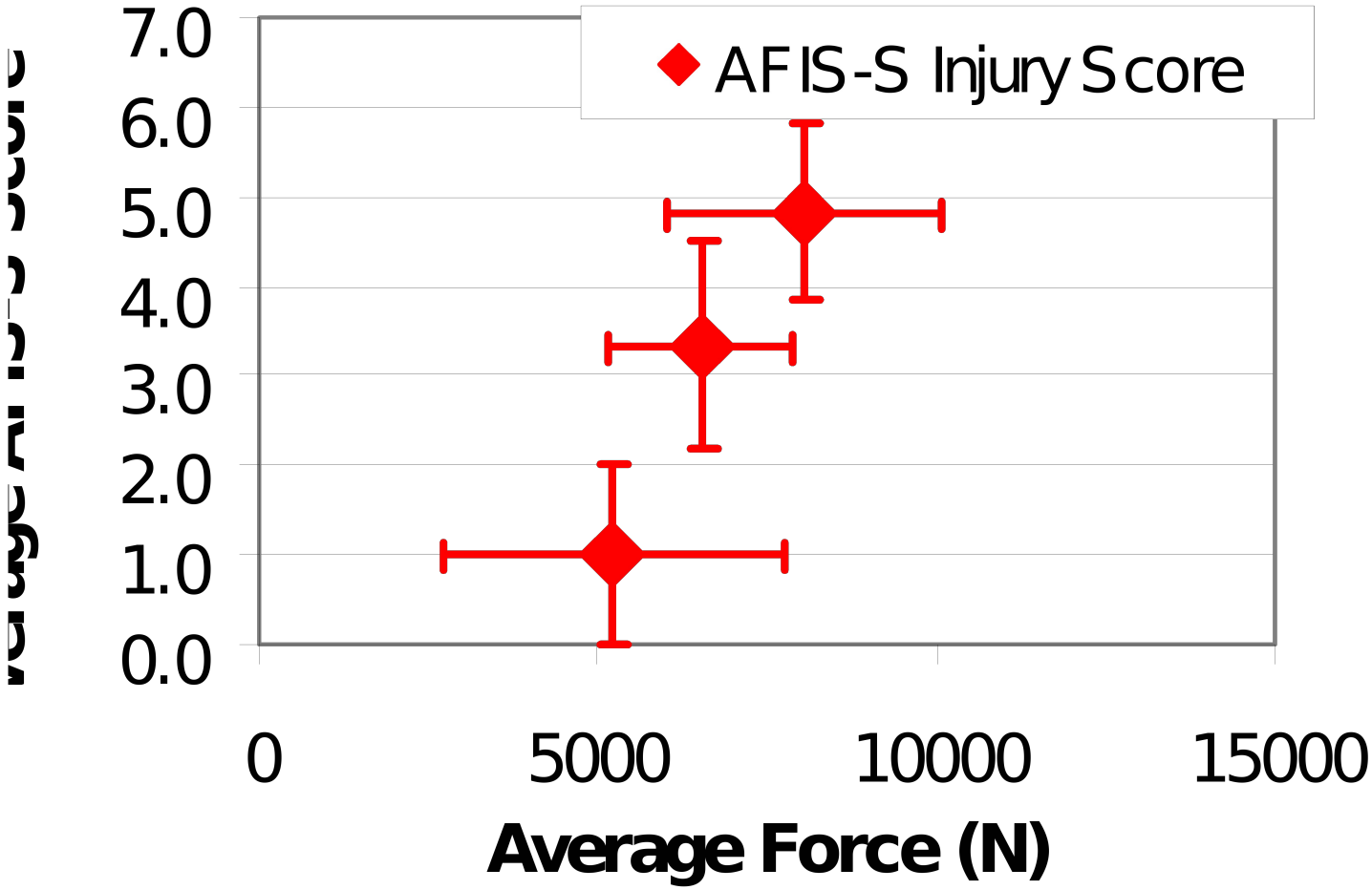
Boot Damage Criterion (BD1-BD3)

- Leap and Leap2003
  - Large boot damage => amputation, low tibia force
- Boot Damage Criterion - Procedure
  - Eliminate boots with penetration into foot compartment (BD2, BD3)
  - Necessary but not sufficient to limit injury risk

Axial Force vs. Test Condition



Injury Score vs. Axial Force



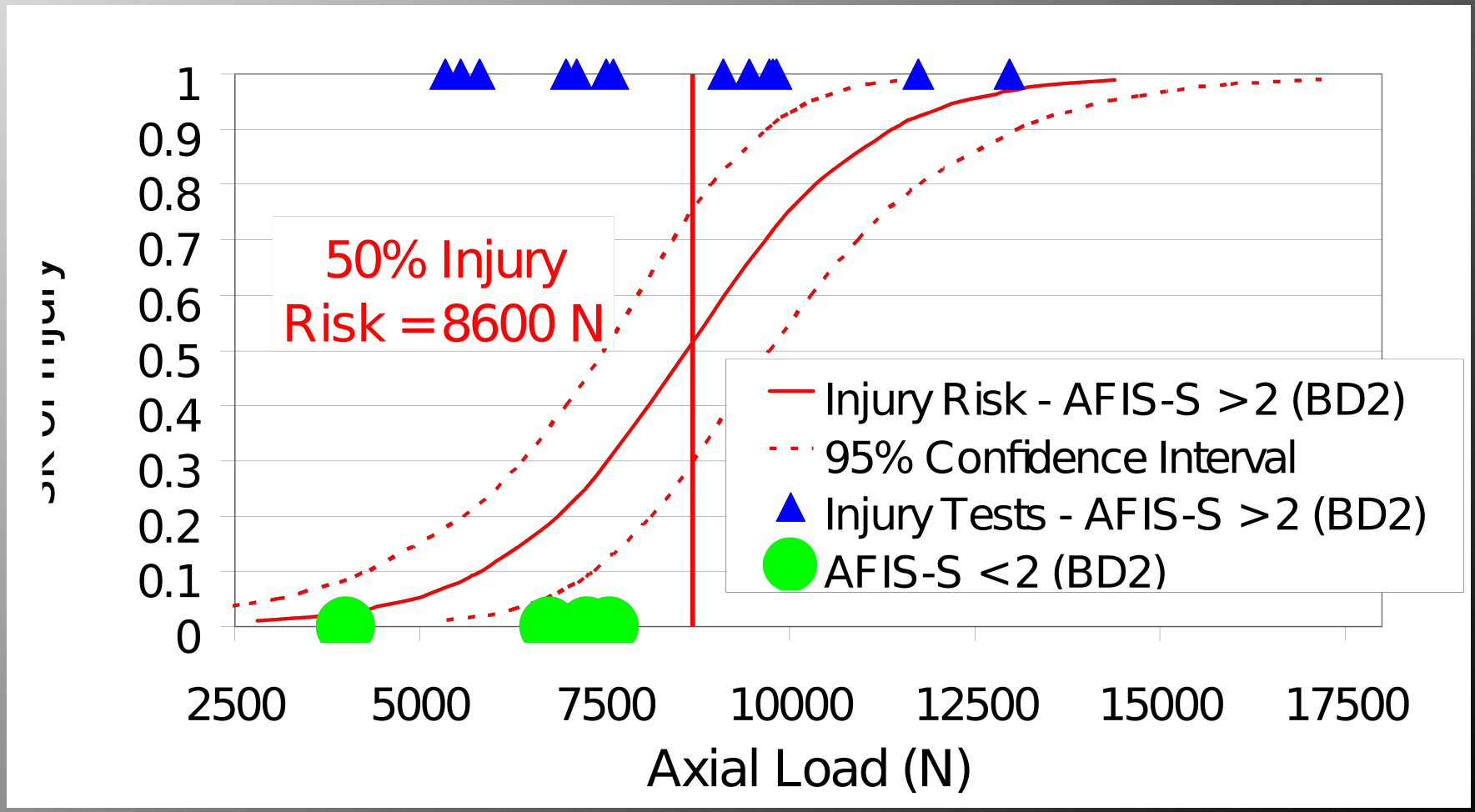
Data – Injury Risk Function

- Compressive Axial Force And AFIS-S To Obtain Risk Function
- Logistic Risk Function:

$$Risk(F) = \frac{1}{1 + \exp\left(\frac{a - F}{b}\right)}$$

  - F = axial compressive force
  - a,b = logistic distribution coefficients

Data – Injury Risk Function



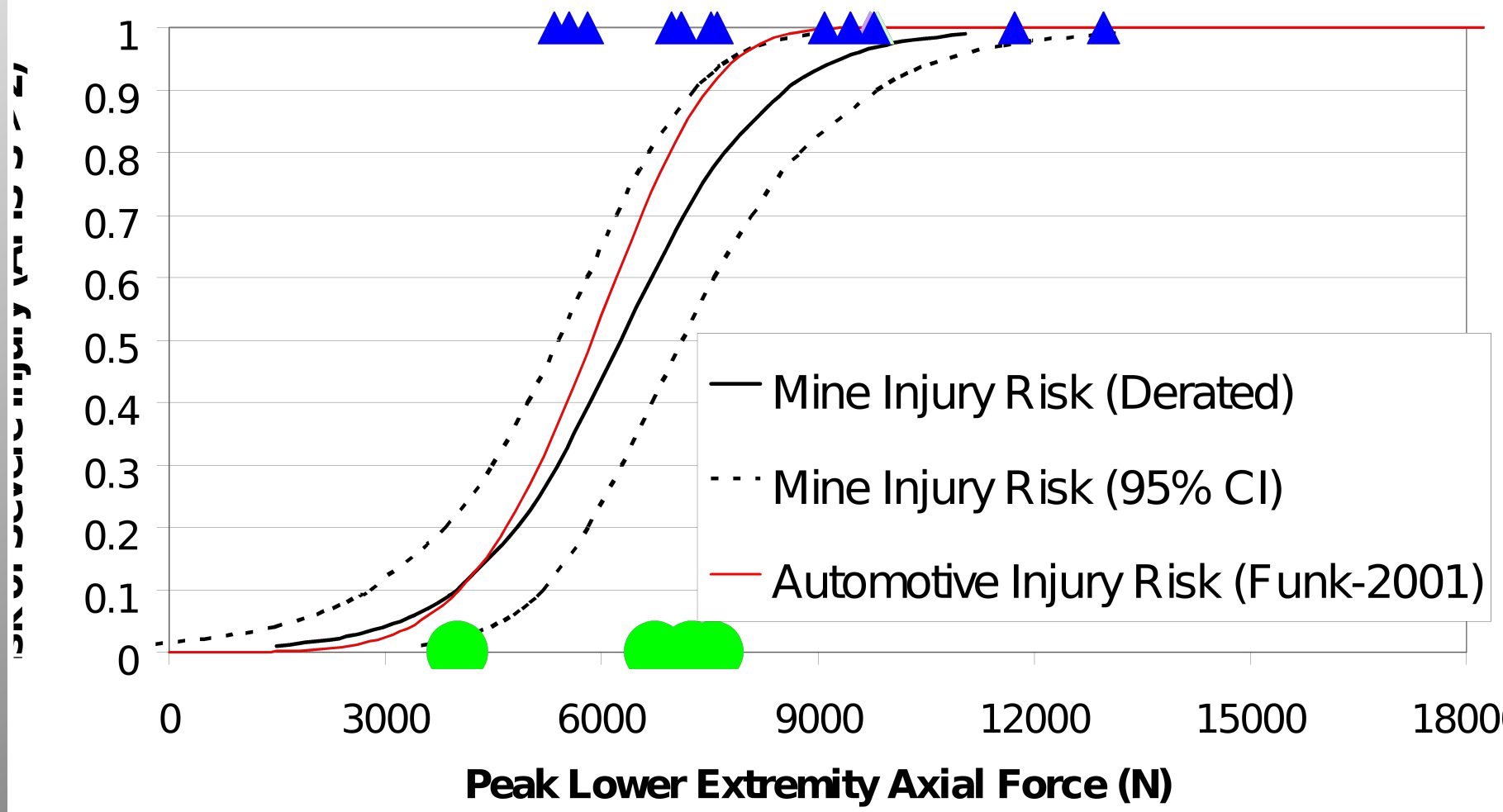
Data – Injury Risk Function

- Injury Patterns Similar to Automobile Injuries
  - Compare risk function with Funk-2000
- Carter and Hayes - Scale Strain Rate

$$S = 68\varepsilon'^{0.06}\rho^{2} \rightarrow \frac{S_{lowrate}}{S_{highrate}} = \left[\frac{\varepsilon'_{lowrate}}{\varepsilon'_{highrate}}\right]^{0.06}$$

  - De-rate the peak force using the coefficient from Carter and Hayes
  - Use the de-rated force to compare with Funk

Comparison with Automotive Lower Extremity Criterion



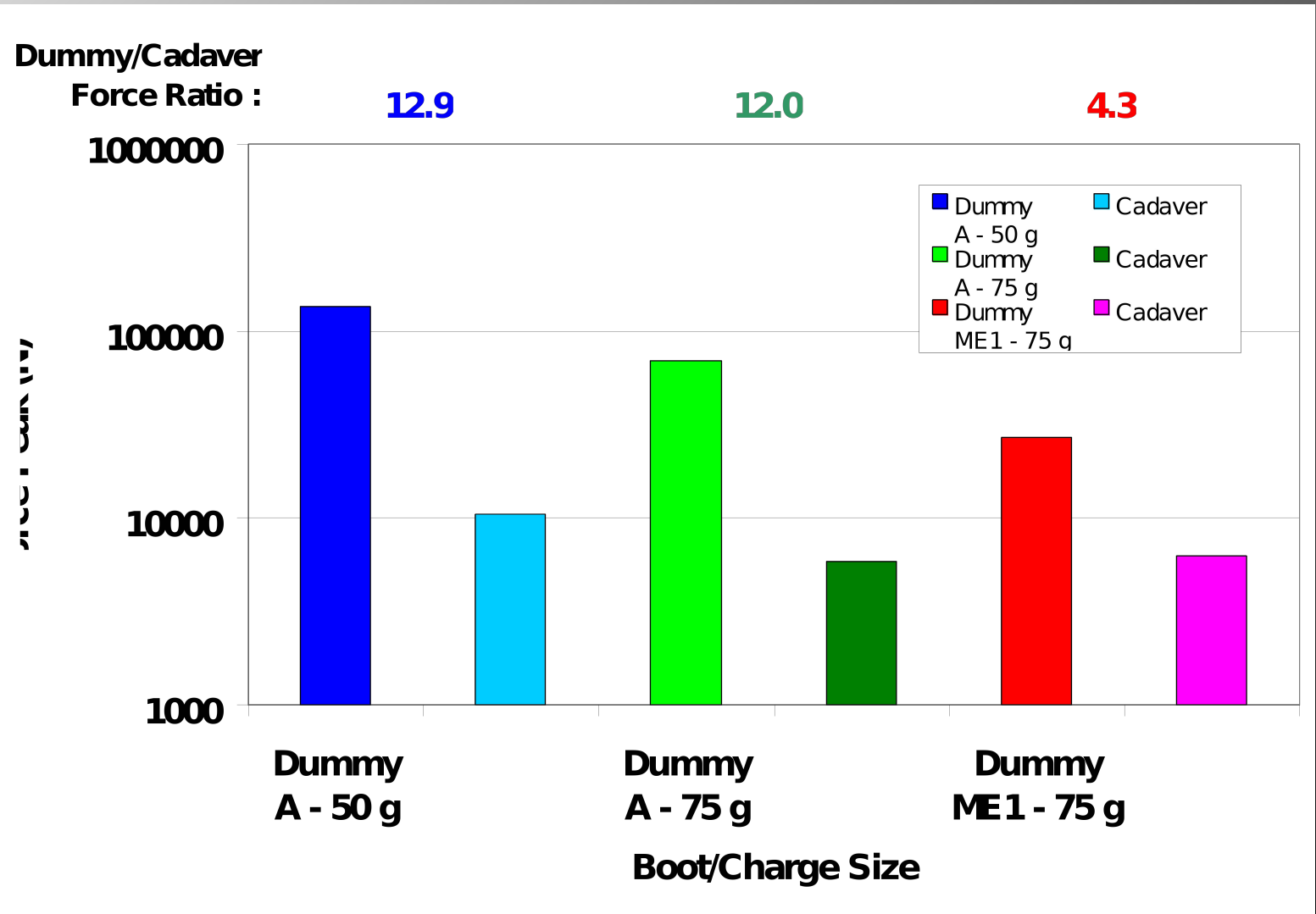
Dummy/Cad Transfer Function

- Used Peak Axial Compressive Loads

$$T = F_{dummy}^{peak} / F_{cadave}^{peak}$$

- Used Dummy To Cadaver Ratio to Scale
  - Appears to be a nonlinear relationship
  - 3 test conditions, 7 total dummy tests
  - Not enough data to establish full relationship

Dummy/Cad Transfer Function



Conclusions

- Robust Test Rig
  - Repeatable, easy to use
- Dummy Foot Performance
  - Mostly robust
  - Minor bending => design correction
- Dichotomous Procedure
  - Boot damage criterion
  - Injury risk function
    - – Consistent with axial automotive criterion
    - – So, can adjust for anthropometry, age

Recommendations and Future Work

- Two-Stage Boot Damage Assessment
  - First phase: only BD1 assessment passes
  - Second phase: evaluate injury risk with force criterion
- More Dummy and Cadaver Tests (5 per condition)
  - reliable transfer function
  - better understanding of scope of data
- More Compliant Element Placed In Dummy Leg
- Test The Effects Of Boot Positioning On Loading And Injury

Disclaimer

- *Though several different commercial boot types were used in this work, this work is not intended to be an evaluation of a specific blast protective boot. Such an evaluation is outside the scope of this study and is not implied by this study.*

Acknowledgements

- *U.S. Army Natick Soldier Center*
- *U.S. Army PEO Soldier*
- *Defence R&D Canada - Valcartier*
- *Defence R&D Canada - Suffield*
- *Uniform Services University of the Health Sciences*
- *Walter Reed Army Medical Center*

Source

The Center for Applied Biomechanics

University of Virginia.

Data – Injury Risk Function Including Original Leap Data